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THE MOON AND THE PLANETS (SPACE PROGRAM)

by V. P. Denisov and V. I. Alimov

"Znaniye" Press, Moscow, 1971

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • FEBRUARY 1973

NASA TT F-767

THE MOON AND THE PLANETS

(SPACE PROGRAM)

By V. P. Denisov and V. I. Alimov

Translation of "Luna i planety (Kosmicheskaya programma)." "Znaniye" Press, Moscow, 1971.
(In the series: Novoye v Zhizni, Nauke, Tekhnike, Seriya "Kosmonavtika, Astronomiya," no. 10)

For Sale by the National Technical Information Service, Springfield, Virginia 22151
$3.00

ANNOTATION

This brochure is devoted to one of the principal directions in cosmonautics, study of the moon and the planets nearest the earth, using space vehicles.

The authors of this brochure present the information known to science today concerning our closest neighbors, planets of the solar system, and tell of the flights of space stations to the Moon, Mars and Venus and the role of man in the exploration and exploitation of space and the immediate objectives in exploration of the solar system.

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THE MOON AND THE PLANETS

(Space Program)

Almost thirteen years separates all of us from that remarkable event /3*
when the Soviet "Luna-1" automatic station, breaking the chains of terrestrial gravitation, for the first time in the history of world cosmonautics penetrated into the boundless expanses of distant space. During the years which have elapsed since then we have become witnesses of a qualitatively new era in study of the celestial bodies closest to the Earth: the Moon, Venus and Mars.

In addition to the classical methods of ground observations in the visible and infrared spectral regions, and also in the radio range, it became possible to carry out scientific investigations in the immediate neighborhood of the Moon, Venus and Mars and on the surface of the Moon and Venus. As a result of these space flights, numerous hypotheses and assumptions concerning the physicochemical characteristics of the Moon, Venus and Mars which only yesterday had been used in interpreting the results of ground investigations and observations had to be discarded. But at the same time new problems arose. These pertained primarily to the nature of the processes transpiring on these celestial bodies or in the space immediately surrounding them.

Solution of the arising problems specifically for each celestial body is extremely necessary for clarifying the peculiarities of chemical composition, heat regime and structure of its atmosphere and surface, and also for more precise determination of the quantitative values of such parameters as temperature and pressure and the patterns of their vertical distribution in the atmosphere and over the surface.

Investigations of the earth's immediate neighbors, the bodies of the solar system, with space vehicles are continuing.

It is entirely obvious that even in the immediate future we will obtain new and valuable research data which will substantially enrich our knowledge concerning the nature of the planets of the solar system and the characteristics of the interplanetary medium.

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*Numbers in the margin indicate pagination in the foreign text.

Our Solar System

The earth is one of the planets of the solar system, constituting a relatively small group of celestial bodies in one of the corners of the universe. /4 In addition to the sun, this system includes nine large planets with satellites, several tens of thousands of small planets (asteroids), comets, and a great number of small meteors. Under the influence of gravitational forces, the large planets revolve around the sun in elliptical orbits which are close to circles in configuration and which lie in the same plane, very close to the ecliptic, the plane of the earth's revolution around the sun.

The sun is situated almost precisely in the center of the planetary orbits. The reason for this is very simple: 99.886% of the mass in the entire system is concentrated in the sun, so that due to its gravitational attraction, it completely determines planetary motions. All the large and small planets move around the sun in the same direction, counterclockwise looking from the direction of the north pole of the ecliptic. Virtually all the large planets, as well as the sun and moon, rotate about their axes in the same direction as the planets revolve around the sun. Venus and Uranus are exceptions.

The planets are negligibly small in comparison with the enormous distances between the earth and the sun. We will only mention that the distance between the earth and the sun, constituting the astronomical unit (a.u.), is approximately 149,600,000 km. The planets are arranged in the following sequence from the Sun: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto.

The distances of the planets from the sun form a regular sequence: the intervals between the planetary orbits increase with distance from the sun. The gravitational interaction between the planets is insignificant. It gives rise to only small perturbations in their elliptical motion.

The planets are divided into two groups, differing from one another in mass, chemical composition, velocity of rotation and number of satellites. The planets closest to the sun (Mercury, Venus, Earth, Mars) are called planets of the earth group. The earth's natural satellite can also be included in this group. Some astronomers also include Pluto in this group.

The planets of the earth group are relatively small; they have a similar chemical composition and consist primarily of heavy elements with a high specific gravity. For example, the mean density of matter in the earth is 5.5 units, with the density of water being used as unity. In the second group, the giant planets (Jupiter, Saturn, Uranus and Neptune), a considerable part of the mass is accounted for by hydrogen and its compound with carbon - methane /5 (CH_4) and with nitrogen - ammonia (NH_3). With an increase in distance from the surface into the depth of these planets, the gaseous state gradually undergoes transition to a liquid condensed state. This occurs at a depth of several hundred kilometers from the surface.

During recent decades planetary astronomy has gone through a period of vigorous development. The use of new methods -- radioastronomy, radar and infrared spectroscopy -- has made it possible to obtain a whole series of interesting and unexpected results and has enabled us to become better acquainted with our neighbors in the solar system. A particularly important role has been played by the fact that such celestial bodies as the Moon, Mars and Venus have become objects of investigations made from space vehicles. Observations of these bodies were made from a close distance for the first time, and landings have been made on Venus and the Moon.

The flights of space vehicles have immeasurably enriched our knowledge concerning interplanetary space, forced a radical re-examination of firmly entrenched ideas concerning the physical conditions prevailing on individual planets, such as Venus and Mars, and also to a considerable degree stimulated the development of terrestrial observation methods which even today serve as an important source of information on the physical properties, atmospheric parameters and characteristics of the surfaces of other planets in the solar system.

Before proceeding to a study of the results of the achievements obtained using space vehicles, we will tell briefly about the closest space neighbors of our planet on the basis of facts accumulated during centuries of astronomical observations and investigations from the earth.

Mercury is the planet closest to the sun and the smallest planet in the solar system. Its mean distance from the sun is 57.9 million kilometers; its geometric figure is close to a sphere with a diameter of 4,840 km. Mercury

travels its orbit around the sun in 88 days, that is, its year is four times shorter than on our earth. For a long time it was assumed that the period of diurnal rotation of Mercury is also 88 days. In this case the same planetary hemisphere would be turned toward the sun and on one-half of Mercury it would be eternal day and on the other side constant night.

However, recent radioastronomical and radar investigations of Mercury made it possible to establish that its period of rotation about its axis is approximately 59 days. Accordingly, there is a change between day and night on this planet.

The deep layers of the planet have a high temperature and on Mercury there may be volcanic activity which could result in formation of mountainous relief on the surface. Recent spectroscopic observations of Mercury revealed the absence of traces of carbon dioxide in the atmosphere, which had been postulated was present. Thus, at present there are no data on the existence of any atmosphere on Mercury. Due to the closeness of the planet to the sun, /6 the temperature of its illuminated surface in the equatorial region was almost 700°K, but after half the Mercurian day it decreases to 600°K, that is, the difference between the daytime and nighttime temperatures is exceptionally great.

Venus is the earth's closest neighbor among the planets of the solar system. This planet has caused ever-greater interest among observers of the sky. Evidently, even at the dawn of astronomy, it became the first object which man learned to distinguish among the infinite number of stars. For the naked eye of a terrestrial observer Venus, which after the sun and moon is the brightest of the celestial bodies, appears as a bright star in the light of the morning or evening twilight. Ancient astronomers long assumed that these were two different stars.

The appearance of telescopic astronomy early in the 17th century enabled Galileo in 1610 to discover the phases of Venus, a phenomenon characteristic of all planets in the solar system and confirming the teaching of Copernicus concerning their motions around the sun.

In the middle of the 18th century, in 1761, the Russian Academician M. V. Lomonosov observed Venus at the time of its transit across the solar disk and for the first time discovered that the planet has a well-developed atmosphere.

The discovery of the Venusian atmosphere by Lomonosov can be boldly categorized as among the greatest of scientific achievements.

During recent decades the intensive development of astronomical spectroscopy, radioastronomy and radar observations of the planets made it possible to obtain new information on Venus, but as before our information concerning it has remained scanty, fragmentary and contradictory.

Venus, second planet in distance from the sun, is at a mean distance of 108 million km. This is about 0.7 a.u. (The a.u. is the mean distance from the earth to the sun.) Venus moves in its orbit at a mean velocity of 35 km/sec, making a total revolution around the sun in approximately 225 earth days. Periodically, once in 1½ years, Venus overtakes the earth and at its maximum approach passes it at a distance of 39 million km. Then both planets diverge, withdrawing a distance of 260 million km from one another.

Radar methods of investigation made it possible to determine the direction and period of characteristic rotation of Venus. It was found that Venus rotates in the opposite direction from other planets of the earth group and the period of its rotation relative to the stars is about 244 terrestrial days. The planetary axis of rotation is virtually perpendicular to the plane along which Venus moves around the sun and this means that there is no seasonal change.

The most surprising thing is that the rotation of Venus is determined by our planet: with each approach of the planets Venus always "looks" at us with the same surface sector. Scientists believe that the reason for this phenomenon may be anomalies in the distribution of planetary mass.

The chemical composition of the Venusian atmosphere was not precisely known. Spectral observations only made it possible to establish that the atmosphere contains a great quantity of carbon dioxide, as well as traces of hydrogen chloride and fluoride. Data concerning the content of water vapor and molecular oxygen were extremely contradictory.

Radar investigations of Venus made it possible to determine with great accuracy the radius of its solid body, but not the radius of its cloud cover, as given by optical observations. It was 6,050 km; this is 0.95 of the earth's radius.

However, all this information no longer satisfied scientists: many aspects of the physics of Venus still remained incomprehensible and unknown. In particular, it was necessary to obtain reliable data on chemical composition of the atmosphere, its constitution, structure, composition and density, distribution of temperature and pressure and their values at the planetary surface, the presence of radiation belts, a magnetic field, etc. /7

In order to obtain answers to these questions, it was necessary to employ new direct methods for investigating Venus: penetration with measuring instruments into its atmosphere with scientific experiments performed in accordance with terrestrial plans and desires. This could be accomplished by only one method: flights of automatic interplanetary stations.

The Moon. From the very beginning of the many centuries of development of astronomy, man has exhibited a high degree of interest in the moon; this was due to the closeness of the moon to the earth, which made it possible to study it more thoroughly and in detail in comparison with other bodies of the planetary type.

In 1610, Galileo viewed the moon through a telescope with 3^{x} magnification and saw mountains and seas on its surface. He used the terms seas (maria) for extensive dark regions, which to him seemed to be great water basins. Since that time three and a half centuries of visual study of the moon have elapsed.

By the late 1940's people knew both much and little about the moon. It was clear that the moon revolves around the earth in an elliptical orbit with a period equal to approximately one calendar month. During this period, called the synodic month or lunar day, one observes a successive change in lunar phases.

A day on the moon lasts more than two terrestrial weeks. During this time, the surface in the equatorial zone is heated by the sun's rays to 130°C. However, during the long lunar night the temperature decreases to -150°C. The distance from the earth to the moon varies in the range from 363,000 to 405,000 km, that is, the moon is a hundred times closer to us than the closest of the planets, Venus, at the time of its closest passage to the earth.

The lunar diameter is only four times less than the earth's diameter, but the mass of our natural satellite is 80 times less than the earth's.

As a result, gravity at the lunar surface is six times less than at the earth's surface. Since it has lesser gravity, the moon cannot hold an atmosphere and water vapor.

The earth and moon exert a great influence on one another; this is determined by the laws of physics and mechanics. The lunar mass, for example, is entirely adequate for changing the earth's figure and causing tides in the seas and oceans. The moon also causes the phenomenon of processional motion of the earth's poles. As a result of change in the earth's figure under the influence of the moon friction is created which slowly lengthens the duration of the terrestrial day.

A new stage in lunar study began during the middle of our century when a new science, radar, came to the assistance of astronomers. By this time, powerful radio telescopes with high directivity and sensitivity had been created.

The first experience in radar observation of the moon from the earth was gained in 1946. Since then radar studies of the moon have been made repeatedly by scientists in different countries. Astronomers have used radar not only to measure the reflecting properties of the surface of our natural satellite, but also in obtaining valuable information on its motion and size. In particular, it was possible to determine the mean distance to the moon with an accuracy of several hundred meters and obtain more precise data on its mass and mean density. It was established using radio waves and measurements in the infrared region that the upper layer of the lunar surface has a low heat conductivity and only very porous or pulverized matter can have such properties.

A discovery of great importance was made by the Soviet astronomer, N. A. Kozyrev, who in November 1958 detected and photographed an eruption of gases in the region of the lunar crater Alphonsus. This phenomenon was clear evidence of lunar volcanic activity. In December 1961, he discovered another active region on the moon. Near the center of Aristarchus Crater he was able to observe the luminescence of gases for several days. Thus, N. A. Kozyrev /8 concluded that at the present time internal forces are active in the lunar interior and that active processes accompanied by heat release are transpiring there.

Investigations made during recent years with particularly sensitive infrared instruments during the time of lunar eclipses, when the lunar surface is not illuminated by direct solar rays, revealed that on the visible side of the moon there are hundreds of "warm" spots whose temperature is tens of degrees higher than the temperature of the surrounding terrain. Some of them have been identified with small craters and also with white spots, probably constituting a cluster of small craters. These observations once again indicated that in the lunar interior deep processes associated with heat release are still transpiring.

All the information concerning the moon given above was obtained using ground methods and research techniques. Man has learned much about the moon. Nevertheless, as before the moon has kept many undisclosed secrets and unsolved mysteries. The results of the ground investigations were by far inadequate for a deep and thorough knowledge of the moon's nature. Many problems of interest to terrestrial science remained open. The development of space techniques afforded new and unprecedented possibilities for a thorough and direct study of the moon.

Mars, a quite large planet of the solar system, is fourth in order from the sun. It is situated at a mean distance of about 228 million km or 1.5 a.u. from the sun. Due to eccentricity of the Martian orbit, this distance varies from 206 to 249 million km. Its distance from the earth varies to an even greater degree: from 56 to 400 million km. Mars makes a total revolution around the sun in 687 earth days and its diameter is 6,780 km. The mass and mean density of the planet are 0.108 and 0.692 of the earth's mass and density, whereas the parabolic velocity at the surface is 5.2 km/sec. Approximately once in two years Mars appears in the sky in a direction opposite the earth. This position of the two planets is called an opposition. Once in 15 to 17 years so-called great oppositions occur; then Mars comes its closest to the earth. The last great opposition was in 1956 and the next will be in August of this year. The equatorial inclination of Mars to its orbital plane is $24^{\circ}48'$; this causes seasonal changes on the planet.

The Martian atmosphere is very rarefied; it consists for the most part of carbon dioxide; no nitrogen has been detected; the quantity of water vapor is insignificant. By means of telescopic observations light-colored regions

called "continents" have been discovered on the Martian surface; these are reddish-orange in color. There are also dark "seas" (maria) of a grayish-green hue. Near the Martian poles there are bright formations called polar caps; they undergo seasonal changes.

Numerous observations of Martian seas have revealed, contrary to the prevailing opinion, that they do not have as smooth a surface as the continents, but are rougher and more uneven.

The surface outlines of Mars are readily distinguishable when taking photographs of the planet through a red filter, but usually they cannot be seen when the planet is photographed through a blue filter. In the latter case the photographs clearly show a haze with strongly expressed light-scattering properties. This haze disappears from time to time. During such a clearing the details of the Martian surface become clearly visible in blue light. An interesting peculiarity of this clearing is that in most cases it appears during the period of the Martian opposition. However, due to great irregularities in the clearings during the oppositions the formulated hypothesis concerning a correlation between the clearings and approaches of the earth and Mars requires more reliable data in order to obtain a confirmation. /9

The maximum temperature at the surface at the time of the closest distance between Mars and the sun in the continental regions of the equatorial zone is approximately 25°C, whereas for the seas it is somewhat greater (up to +30 - 33°C). Temperature variations during the course of the Martian day attain 80 - 100°C. The nighttime surface temperature is -70 -100°C. Data on physical conditions on Mars known to science at the present time do not contradict the possibility of the existence of primitive forms of plant life on this planet.

Mars has two satellites, whereas Mercury and Venus have none. The satellite closest to Mars, Phobos, has a diameter of 16 km; it is at a distance of 9,500 km from the center of the planet and revolves around it in 7 hours 40 minutes. The more distant satellite, Deimos, is smaller; it has a diameter of about 8 km. It is situated at a distance of about 24,000 km from the planet and revolves around it in 30 hours 20 minutes.

One of the phenomena on the Martian surface, the so-called "Martian canals," are of the greatest interest. During the Martian opposition of 1877,

the Italian astronomer Schiaparelli discovered on the planet a network of narrow dark bands intersecting the orange-red regions of the planet in different directions. He called these bands "canals."

Interest in the new discovery was enormous, but later the French astronomer Antoniadi demonstrated that no geometric network of canals exists and that the canals themselves are not continuous lines. This was fully confirmed by subsequent telescopic observations of Mars. With good, very clear images the "canals" usually break down into irregular clusters of individual dark spots or points.

Accordingly, what are the canals? Even today we cannot give a reliable answer to this question. These are possibly cracks in the planetary crust, as postulated by some scientists. It is probable that they consist of a great number of details, poorly distinguishable, but it cannot be excluded that the canals are actually more moist places along which some vegetation, unknown to us, appears during spring and summer. Further observations and investigations of Mars using space vehicles will enable us to probe all its secrets and mysteries.

Jupiter is the planet next in distance from the sun after Mars. Its mean distance from the sun is about 778 million km or more than 5 a.u. Jupiter is the largest planet in the solar system; its diameter is approximately 144,000 km (11.26 times the earth's diameter); its volume is 1,345 times greater than the volume of our planet. Jupiter and its 12 satellites revolve around the sun with a mean velocity of not much more than 13 km/sec and makes one revolution in approximately 12 earth years.

The axis of Jovian rotation is almost perpendicular to its orbital plane; there is no sharply expressed change in seasons. The period of diurnal rotation of Jupiter is not much less than 10 hours. The density of Jupiter is 1.3 g/cm^3 and its mass is 318 times greater than the earth's mass. As a result, Jupiter has strong gravity and can hold even the lightest gases in its atmosphere. The surface of Jupiter cannot be seen because it is hidden beneath a thick atmospheric layer consisting of hydrogen, helium, methane and ammonia.

On Jupiter there are clouds which like on the earth change in configuration and position. In addition to clouds, Jupiter has some constant formations,

the so-called Great Red Spot, having an oval configuration with a diameter of approximately 10,000 - 40,000 km, and some dark bands. The nature of this longitudinally drifting formation is unknown. More than 15 years ago radio telescopes picked up the radio emission of Jupiter. Later it was discovered that the planet is surrounded by two great radiation belts extending for a distance of three radii in the equatorial plane. This circumstance indicates /10 that Jupiter has a magnetic field. Jupiter receives approximately 25 - 30 times less heat from the sun than does the earth.

The mean temperature of the outer layers of Jupiter is estimated at approximately 130 - 140°K. Jupiter and its 12 satellites constitute a whole system of cosmic bodies. Four of them are giants. For example, the largest of them, Ganymede, with a diameter of 5,600 km, is larger than the planet Mercury. Some Jovian satellites revolve around the planet in retrograde motion, that is, opposite the revolution of the planet and other satellites. The reasons for this direction of motion of these Jovian satellites are still not reliably known.

Saturn has a low density and specific gravity. Accordingly, in its volume it is 760 times but in its mass only 95 times greater than our earth. Saturn has the greatest flattening at the poles of any of the known planets (1/10). It is at a distance of 9.5 a.u. from the sun (1,427 million km), that is, it is twice as far as Saturn. Saturn makes one revolution around the sun in 29.5 earth years. Its mean velocity of motion in orbit is 9.6 km/sec. As in the case of Jupiter, the Saturnian surface cannot be seen. Only the physical characteristics of the figure formed by opaque layers of the atmosphere have been determined.

The diameter of this figure is 120,500 km, that is, 9.4 earth diameters. It is postulated that atmospheric depth and composition are close to those of /11 Jupiter; the radius and nature of the solid surface of Saturn are also unknown. The time for rotation of Saturn about its axis is approximately 10 hours 40 minutes. The temperature of the outer layer of the Saturnian atmosphere is very low: it is approximately 100°K. The principal phenomenon of Saturn which distinguishes it from among the other planets is its rings, lying in the equatorial plane. The outer ring A, having a radius of 120,000 - 140,000 km, is separated from the middle ring B (with a radius of 90,000 - 117,000 km) by Cassini's gap. The inner ring C, closest to the planet, has a radius of

TABLE OON

Planet	Diameter (equatorial		Inclination of equatorial plane to orbital plane	Temperature, °C			Number of satellites	Mean orbital velocity, km/sec
				Equilibrium		Radiometric (for warmest zone)		
	km	Diams of e equa uni		T_1	T_2			
Mercury	4,840	0.	0°	+358	+172	+400	0	47.8
Venus	12,400	0.	?	+191	+ 54	+ 57	0	35.0
Earth	12,756	1.	23.5°	+119	+ 4	-	1	29.76
Mars	6,780	0.	25.2°	+ 43	− 51	+ 15	2	24.11
Jupiter	143,640	11.	3.1°	-100	-151	-140	12	13.05
Saturn	120,500	9. s	28.7°	-145	-183	-150	10	9.64
Uranus	53,400	4.	98°	-184	-210	-200	5	6.78
Neptune	49,600	3.	29°	-201	-222	?	2	5.47
Pluto	5,500 ?	0.	?	-211	-229	?	?	4.74
Moon	3,476	0.	-	-	-	-	0	-

70,000 - 90,000 km. All the rings consist of meteor bodies with a diameter of about one meter.

The thickness of the rings is estimated at from 0.3 to 5 km. In addition to the rings, Saturn has 10 satellites, of which the largest is Titan. Its diameter is about 5,000 km. Titan has a relatively dense atmosphere consisting primarily of methane. It is particularly surprising that Titan has a mass only 1.8 times greater than the moon. It is postulated that Titan in some way acquired its atmosphere from Saturn.

Uranus and Neptune are planets similar to one another, being like twins. They are giant planets moving in very remote regions of the solar system. /12 Their diameters are approximately four times greater than the earth's diameter. Due to the great distances, it is very difficult to discriminate any details on the surface of Neptune, whereas on Uranus one can detect only poorly differentiated zones. Uranus is at a mean distance of 19.2 a.u. from the sun (2.870 million km), whereas Neptune is at a distance of 30.1 a.u. (4.496 million km). Both planets are surrounded by atmospheres similar to the atmospheres of Jupiter and Saturn.

The period of revolution of Uranus around the sun is about 84 years; the period of rotation about its own axis is 10.7 hours. These parameters for Neptune are 165 years and 15.8 hours. The temperatures on these distant planets are very low. Uranus has five satellites and Neptune has two. In one respect Uranus is an anomalous planet. The plane of its revolution, which at the same time serves as the plane of orbital motion of its satellites, is tilted almost at a right angle (98°) to the plane of Uranian revolution around the sun, that is, all motions are essentially retrograde.

Pluto, the most distant planet in the solar system, was discovered relatively recently, in 1930. Pluto seems like a monstrous dwarf among the giant planets. Our information concerning it is extremely limited. The mean distance from the sun is about 40 a.u. (5.947 billion km). The time required for Pluto to revolve in orbit is 248 years. Planetary temperature is estimated at approximately 50 - 60°K. The Plutonian disk cannot be observed telescopically. Its diameter is probably 5,500 km, which in combination with its mass (0.925 of the earth's) leads to the highest mean density for the planets -- 50 g/cm^3. No satellites have been detected around Pluto.

Small planets (asteroids), comets and meteors. Asteroids revolve around the sun primarily between the orbits of Mars and Jupiter. Most of the asteroids are at a distance of about 2.5 a.u. from the sun and their period of revolution around it is five or six years. More than 6,000 asteroids have now been discovered, but orbits have been computed for only 1,700 of them, and they have been listed in a special catalogue of the minor planets. Some asteroids have such elongated orbits that they pass close to the orbit of Venus (for example, Hermes) and even pass beyond the orbit of Mercury (the asteroid Icarus approaches the sun to a distance of 0.19 a.u.). The largest asteroid, Ceres, has a diameter of 770 km; the others are far smaller. Many of them are amorphous blocks with a transverse diameter of several hundred meters.

The solar system includes 10^{11} comets. They are small bodies (from several hundred meters to several kilometers), consisting of different gases frozen to a solid state: ammonia, methane, carbon dioxide, and others. Individual formations of meteor matter are embedded in the "ice nucleus." With approach of the comet to the sun, the gases evaporate and under the influence of the sun's rays form a giant luminescent tail. Comets usually disintegrate gradually and cease to exist.

Meteors can be classified into groups: meteor streams (swarms) and meteors proper. The orbits and parameters of motion of some meteor swarms in the solar system are known and meetings with them can be predicted. However, meetings with meteors are always random. For space vehicles a collision with meteor particles and meteors, which can occur with a velocity of several tens of kilometers per second, is a serious danger. In interplanetary space there are a great number of meteors and meteor streams unknown on the earth. It is impossible to predict their motion and the possibility of encountering them.

Principal Stages in Space Exploration of Celestial Bodies /13

Man's study and conquest of interplanetary space and celestial bodies is occurring in definite stages, without whose successive solution there could be no further development of cosmonautics. One of the principal stages is attaining second cosmic velocity (about 11.2 km/sec), necessary for interplanetary flights within the solar system.

Flight of the first Soviet automatic station "Luna-1" in January 1959 revealed to the entire world that this threshold had been successfully overcome: in a fly-by at a distance of about 6,000 km from the earth's natural satellite, the "Luna-1" automatic station left the sphere of the earth's attraction and became history's first artificial planet in a circumsolar orbit.

More than 12 years have elapsed since January 1959. This is a very short time on the scale of human history, but space exploration has taken enormous forward strides during these years. Interplanetary automatic stations blazed the cosmic trajectories Earth-Moon, Earth-Venus, Earth-Mars and Earth-Moon-Earth. Overcoming terrestrial attraction, space rockets attained the moon, flew around it, photographed its far side, invisible from the earth, made a soft landing on the surface of our natural satellite, went into orbit as artificial lunar satellites, returned samples of lunar ground to the earth, and finally, delivered to the moon a mobile self-propelled vehicle which over a period of many months conducted a broad program of scientific and technical investigations on the lunar surface. Flights of manned spaceships to the moon have also been successfully executed.

Automatic stations have flown to Venus, made repeated soundings of its atmosphere, and have made a soft landing on its surface. The Martian surface has been photographed from fly-by trajectories and new scientific data on the nature of this planet have been obtained.

During recent years several tens of automatic stations have been launched to the moon and planets from the Soviet Union and the United States. Space research has been accomplished primarily by the use of automatic stations. Today this has proven itself, is justifiable and understandable. The fact is that automatic vehicles can penetrate more easily into remote and inaccessible regions of the universe and obtain radiotelemetric and even television

information concerning these regions and the physical processes transpiring there. This does not mean that exploration of space, the moon and the planets of the solar system can and will take place without the direct participation /14 of man. In the future man's participation may be needed in solving some problems.

The Soviet program of interplanetary flights is multipurpose, broad, and at the same time successive and planned. Gradually, step-by-step, the technical complexity and scientific importance of Soviet space experiments is increasing. Automatic vehicles are assigned the leading role in conducting this research.

The scientific and technical problems soluble by Soviet automatic stations are formulated taking into account accumulated information and become more complex with each successive launching. In the process of exploring celestial bodies by automatic vehicles, in the examples of the Moon, Venus and Mars, it is possible to define the principal stages governed by the capabilities of rocket-space systems and the development of cosmonautics.

During the first stage there is exploration, limited in time, with approach of the space vehicle to a celestial body, with either impact or a flight around it.

During the second stage of exploration, it is possible to solve more complex problems relating to the delivery of instruments to the surface of the explored body or into the orbit of an artificial planetary satellite.

During these stages scientific information can be sent to the earth only by radio and television-telemetric channels.

The third stage involves solution of a complex technical problem: return of the automatic station to the earth from a satellite orbit around the explored celestial body or from its surface. In this case the information is delivered directly to the earth. It can be assumed that these stages will also be characteristic for study of other celestial bodies.

In exploring space, the moon and planets, our country has objectives which are determined by the needs of science and the national economy and which serve the interests of all mankind.

Space Explorations of the Moon

For more than 12 years the moon has been the object of intensive exploration by space vehicles. This exploration has been carried out by the two leading space powers in the world: the Soviet Union and the United States. They have launched to the moon and onto the moon about 50 space vehicles, of which about 85% were automatic vehicles and 15% manned. /15

Automatic vehicles, which quite effectively and economically advantageously make it possible to carry out scientific investigations at great distances from the earth under extremely complex conditions and with relatively low cost, have been widely used and will be used in the future for the initial reconnaissance penetration into still little-explored and inaccessible regions of space. Their effectiveness in exploring the moon has been demonstrated, for example, in flights of Soviet automatic stations of the "Luna" and "Zond" series. Space vehicles designed for different missions have made extensive investigations of circumlunar space and the physical characteristics of our natural satellite. All these investigations have yielded very rich scientific material which has considerably broadened our knowledge of the moon and in some cases has changed earlier prevailing concepts concerning this celestial body.

The experience acquired by modern cosmonautics in the course of space explorations of the moon is evidence that its study is proceeding in successive stages. This includes study of the space surrounding the moon from a fly-by trajectory or flight around the satellite, reaching the lunar surface (hard landing), a soft landing on the moon, putting space vehicles into lunar artificial satellite orbits, and delivery of automatic mobile vehicles to the lunar surface.

Important scientific experiments in the field of exploring the interplanetary medium were made early in January 1959 by the "Luna-1" Soviet automatic interplanetary station; its flight was a new stage in the development of world cosmonautics, opening the era of flights to other celestial bodies.

The first experience in studying another celestial body from aboard a space vehicle was obtained as a result of flight of the Soviet automatic station "Luna-3," which for the first time in history photographed the far side

of the moon, putting a mass of unique information into the hands of scientists.

Lunar exploration from a fly-by trajectory was continued in the United States by means of space vehicles of the "Pioneer" and "Ranger" types and also by the Soviet "Luna-4" and "Luna-6" stations. Flight of the Soviet automatic station "Zond-3" can be considered the concluding scientific experiment in the first stage of space exploration of the moon. In July 1965 this station photographed the far side of the moon, including that part which had not been covered in the survey by the "Luna-3" station. Such was the first stage in study of the moon by space vehicles. This yielded extensive scientific information which brought the earth's scientists closer to an understanding of the composition of circumlunar space, the structure of the lunar surface, and /16
the nature of different features on its surface. Flight of the second Soviet space rocket with the "Luna-2" station, the first to reach the surface of our natural satellite, opened the next stage of lunar exploration. The first American artificial object reaching the lunar surface was the "Ranger-4" space probe, launched from the earth almost 2½ years after the "Luna-2" flight. However, the "Ranger-4" flight was unsuccessful: it did not fly by in the computed trajectory, did not fulfill the flight program and fell on the far side of the moon. In general, it happened that the launchings of the first six American "Ranger" vehicles were unsuccessful for one reason or another. Only the "Ranger-7" probe, in July 1964, was the first to carry out the planned program. Seventeen minutes prior to falling on the moon it began to transmit telephotographs to the earth, many of which are of considerable interest.

The "Ranger-8" and "Ranger-9" were launched to the moon during the first half of 1965. Both vehicles performed their assigned missions: they reached the lunar surface and transmitted a series of photographs to the earth. The flights of these space vehicles made it possible to obtain a large number of photographs of three regions of the visible surface of the moon, whose distinguishable details were approximately 1,000 times smaller than when observed through the best terrestrial telescopes. Analysis of the photographs taken from Soviet and American stations revealed that the lunar surface as a whole was very smooth. This smoothness of relief features can evidently be attributed to the singular erosion caused by micrometeorites and streams of high-

energy particles, by the solar wind. It was found that on the moon there is prevalence of sunken relief forms: craters, pits, and troughs, whereas highlands are encountered less frequently.

Further lunar investigations during this stage were carried out in the Soviet Union during flights of the automatic stations "Luna-5," "Luna-7," and "Luna-8." In addition to investigations along the flight trajectory, all these stations were also used for solving a number of fundamental problems associated with perfecting a soft landing on the lunar surface.

The second stage in cosmic exploration on the moon was completed in 1965, that is, six years after its onset. As a result of extensive scientific investigations carried out during this stage, information was obtained which is of unquestionable scientific value even at the present time, although it could not solve the problems which had long interested the earth's scientists as to the nature and strength of lunar ground, the possibility of landing automatic stations on the moon, etc. Answers to all these questions were provided by space vehicles in the third stage of lunar investigations. /17

As is well known, one of the most complex problems in cosmonautics is making a soft landing on the surface of a celestial body without an atmosphere which could be used for braking a space vehicle. For the first time in history this problem was successfully solved by the Soviet "Luna-9" automatic station in February 1966. Unique terrain panoramas were transmitted from the landing site for different solar angles above the horizon. For the first time seven radio communications contacts were made from the lunar surface for the transmission of scientific information. The American "Surveyor-1" space vehicle in June of this same year also made a soft landing in the region of Oceanus Procellarum, not far from Flamsteed Crater. The information which it transmitted, like from the "Luna-9" station, again confirmed the absence of dust on the lunar surface and an adequate strength of its component materials for the landing of spaceships.

A new attempt to land on the lunar surface undertaken soon thereafter in the United States with the "Surveyor-2" vehicle ended in failure: upon approach to the moon the vehicle began to tumble and crashed against its surface.

As a result of the successful lunar landing of the second Soviet automatic station, "Luna-13," unique data were obtained on the physicomechanical

properties of the lunar surface layer by means of scientific instrumentation (mechanical ground sampler, dynamograph and radiation densimeter). The station determined reflectivity of the lunar surface for cosmic rays and was used in transmitting new panoramas of the lunar surface to the earth. The American "Surveyor-3" vehicle landed and made investigations of the mechanical strength of lunar ground. The fourth "Surveyor" failed to land on the lunar surface. However, the United States later made soft landings of three other vehicles in this series.

On the basis of lunar investigations made during this stage by Soviet and American space vehicles, it was possible to determine the mechanical, physical and chemical characteristics of lunar ground and it was established that the surface lunar ground consists for the most part of volcanic rocks similar to those found on earth.

Solution of the problems involved in creating artificial lunar satellites merits particular attention. This extremely difficult problem was solved for the first time on 3 April 1966 when the Soviet automatic station "Luna-10" was successfully put into a circumlunar orbit. Lunar investigations from artificial satellite orbits were continued by the Soviet space vehicles "Luna-11," "Luna-12," "Luna-14" and "Luna-15," as well as by American vehicles of the "Lunar Orbiter" series. /18

Lunar artificial satellites made it possible to obtain detailed photographs of large areas of the visible and far sides of the moon. These photographs constitute a highly important source of information on the lunar surface. Anomalies of the lunar gravity field, configuration of the moon, and its radiation conditions were also studied. New information was obtained on magnetic phenomena and the density of meteor matter and plasma in circumlunar space. As a result, a conclusion of primary importance was drawn: meteorite and radiation conditions near the moon constitute no serious threat for carrying out manned space flights.

The next stage in lunar exploration by space vehicles was opened by automatic and manned flights with return to the earth. A major step in this direction was the flights of the Soviet space vehicles "Zond-5" and "Zond-6"; these, flying around the moon, successfully returned with second cosmic velocity to the earth and delivered a great volume of scientific information.

Thus, the earth-moon-earth trajectory was travelled for the first time.

Flights of the Soviet automatic stations "Zond-7" and "Zond 8" constitute a further continuation of the scientific-technical experiments during this stage.

The main attention of scientists was drawn to the capability of the vehicles in this series to bring home all the priceless experimental and photographic material obtained during the travels.

Manned flights to the moon with return to the earth played an important role in study of the moon. This problem was successfully solved for the first time in July 1969 by the American "Apollo-11" spaceship carrying the astronauts, N. Armstrong, M. Collins and E. Aldrin aboard.

The lunar module of the "Apollo-11" spaceship, carrying the astronauts Armstrong and Aldrin, made a soft landing on the moon, took off from the lunar surface and rejoined the main module, which with the astronaut Collins made flights in circumlunar orbit during the period of landing of the lunar module on the lunar surface.

Thus, man for the first time walked on the surface of another celestial body, our natural satellite, the moon. This happened almost ten years after the time when a banner with the State Seal of the Soviet Union was delivered to the moon in September 1959.

The first expedition of humans to the moon, returning samples of lunar ground to the earth, is one of the important links in the long chain of space events associated with exploration of our natural satellite. It was prepared by the entire course of successive study of the moon by mankind. Several other expeditions later flew to the moon. /19

Flights of the Soviet "Luna-16" and "Luna-17" stations were of special value. In September 1970 the Soviet "Luna-16" automatic station solved a highly complex scientific-technical problem in cosmonautics: collecting samples of solid rock from a celestial body of the solar system by automatic apparatus and returning these samples to the earth.

The automatic station was launched from the earth on 12 September 1970, went into a selenocentric orbit on 17 September, and after maneuvering on

20 September made a soft landing in the region of the Mare Foecunditatis. After presence on the moon for 26 hours 15 minutes, on 21 September the station was launched from the lunar surface and reached the earth on 24 September.

The "Luna-16" automatic station, using a special drill which penetrated up to 35 cm into the lunar rock, took unconsolidated surface material from the region of the Mare Fecunditatis; this regolith was delivered to scientific laboratories on the earth. There, using the latest research methods, geochemists determined 70 chemical elements present in the ground and formulated a detailed classification of the rocks making up the lunar surface.

The chemical composition of the lunar ground returned by the "Luna-16" station is given in Table 2. This table, as a comparison, gives data from a chemical analysis of lunar rocks returned to the earth by the crew of the "Apollo-12" ship.

TABLE 2. CHEMICAL COMPOSITION OF LUNAR ROCKS

Chemical compounds	Basaltic rock ("Luna-16")	Fine fraction ("Luna-16")	Basaltic rock ("Apollo-12")	Fine fraction ("Apollo-12")
SiO_2	43.8	41.7	40	40
TiO_2	4.9	3.39	3.7	3.1
Al_2O_3	13.65	15.32	11.2	14
FeO	19.35	16.8	21.3	17
MgO	7.05	8.73	11.7	12
CaO	10.4	12.2	10.7	10
Na_2O	0.33	0.37	0.45	0.40
K_2O	0.15	0.10	0.065	0.18
MnO	0.2	0.21	0.26	0.25
Cr_2O_3	0.28	0.31	0.55	0.41
ZrO_2	0.04	0.015	0.023	0.09

It follows from an analysis of Table 2 that the chemical composition of /20 the lunar ground returned by "Luna-16" and "Apollo-12" is close. It corresponds to rocks of the basaltic series and approaches the composition of primitive

terrestrial basalts. Investigations of samples of lunar ground are continuing in institutes of the USSR Academy of Sciences.

Flight of the "Luna-16" station constitutes an outstanding achievement of Soviet science and technology, opening up new and broad possibilities for conducting systematic scientific investigations of celestial bodies by the use of automatic vehicles.

The successful flight of the Soviet automatic station "Luna-17," which in November 1970 delivered the world's first mobile automatic vehicle, the lunokhod, to the lunar surface, constitutes a qualitatively new stage in lunar exploration. Here was a particularly clear demonstration of the enormous possibilities afforded to mankind by automatic vehicles and control systems.

The "Lunokhod-1" traveled more than ten kilometers along the lunar surface, exploring an extensive region of the desert plain of the lunar Mare Imbrium. An enormous number of photographs of the lunar landscape was transmitted to earth. This extensive information will enable scientists to learn much which is new and to compile a highly detailed map of the explored part of the moon. The lunokhod also transmitted to earth a great amount of information concerning composition of the lunar surface, structure of the lunar ground, and its mechanical, physical and chemical properties and its carrying capacity. Data on the x-radiation of different celestial objects and investigation of cosmic rays are of great interest.

It is difficult to overestimate all the extensive possibilities which we are afforded by the world's first mobile lunar laboratory outfitted with the most modern apparatus. It makes it possible to investigate the most diverse regions of the lunar surface.

Much more time must be expended on processing and analyzing the scientific data collected by the "Lunokhod-1." But even now it has become entirely clear that the practice of studying celestial bodies by the use of automatic vehicles has completely justified itself during this stage in the development of cosmonautics.

It will be possible to give a complete evaluation of all the importance of this stage only in the future when man, in addition to the investigations

made today, will proceed to direct exploitation and settlement of the moon. Lunokhods will be used extensively in the construction of scientific bases, settlements and lunar cities; they will transport freight, act as bulldozers, dig basins, perform repair work, and do much else.

It became obvious that in the course of further space explorations, it will be possible to determine the subsequent stages in lunar exploration, especially the desirability of organizing long-term manned bases and settlements on the moon. /21 Although it is still a long time before we will see man's practical exploitation of the moon, our natural satellite can be used as an "intermediate platform" for further space exploration. In this case, effectiveness will be achieved because this "platform" was created in space by nature itself. In this sense no expenditures are required from mankind. The moon is an entirely reliable base with a well-studied and faultlessly operating system for orientation relative to the earth and sun.

For example, by creating a lunar automatic observatory we can make measurements of cosmic radiation, the solar wind, corpuscular streams, and other parameters distorted by the earth's magnetic field, and also observe the solar "constant" and its variations. The moon is more convenient for this purpose than are artificial earth satellites because the possibility for prolonged continuous measurement is ensured.

Simultaneously with investigations of terrestrial, solar and space parameters a lunar observatory will make it possible to measure many physical characteristics of the moon, lunar ground and lunar seismicity. From the moon it will be easy to study solar-terrestrial relationships and processes transpiring in the upper layers of the atmosphere. For example, the moon can be used in making simultaneous observations of synoptic processes developing over half the earth and in obtaining global maps of the cloud cover over the entire earth, etc. Long-term manned stations will probably be established on the moon; these will be for investigating the physical and geological characteristics of our natural satellite, studying the prospects of using the moon for organizing and conducting industrial processes (metallurgy, chemistry, etc.) which are complex and harmful under terrestrial conditions, and also the possibility of using the moon as a space refueling station for interplanetary rocket systems or as a center for modern space communication and navigation

systems. In short, the possibilities of using the moon for the needs of mankind are virtually inexhaustible.

Further investigations of the moon will undoubtedly be made by both automatic vehicles and with man's participation. Each new flight will multiply our knowledge concerning the moon and will bring new information concerning the universe.

Space Explorations of Venus

/22

The first exploration vehicle sent by man to another planet of the solar system was the Soviet automatic interplanetary station "Venera-1," launched in February 1961.

In May 1961 it reached the region of Venus, passed at a distance of about 100,000 km from its surface, and entered a solar satellite orbit. The Earth-Venus interplanetary trajectory was blazed.

On 27 August 1962 the "Mariner-2" space probe was launched in the direction of the planet Venus from the United States; in December of that same year it passed at a distance of 40,000 km from the planetary surface and transmitted some new information concerning Venus, although not as much as hoped for. It was confirmed as a result of the launchings that the planetary surface temperature is very hot, atmospheric pressure is 20 times greater than on the earth, and atmospheric density is great. The cloud layer is about 25 km thick and is at an altitude of approximately 70 to 100 km above the surface. It was established on the basis of instrument readings that Venus evidently has no magnetic field.

In November 1965, for the first time in history, our country launched a group interplanetary flight with the "Venera-2" and "Venera-3" space probes. These two launchings were not simply duplications of one another. The objectives of the flight were different for each station: the "Venera-2" was to fly by Venus on the side illuminated by the sun at a distance of not more than 40,000 km from its surface, whereas the "Venera-3" was to reach the planetary surface. The implementation of the missions assigned the stations required a very high accuracy in putting the interplanetary vehicles in a trajectory for reaching Venus. In order to ensure the required trajectory accuracy provision was made for making in-flight motion corrections.

However, the accuracy in launching the "Venera-2" station was good and therefore there was no need for correcting its trajectory. In February 1966 the "Venera-2" flew over the illuminated part of the planetary surface. The distance to it was 24,000 km. Late in December 1965, when "Venera-3" was situated at a distance of 12.9 million kilometers from the earth, the solar-stellar orientation system was used in correcting its trajectory; this enabled

the station to reach the Venusian surface on 1 March 1966 and deliver there a pennant with the State Seal of the Soviet Union. Thus, for the first time in mankind's history, a vehicle created by human hands made an interplanetary flight and reached the surface of another planet. /23

An outstanding success in studying Venus and a new and significant contribution to the development of cosmonautics was flight of the "Venera-4" automatic station. The station was launched on 12 June 1967. Two days later the "Mariner-V" space probe was launched toward Venus from the United States. On 18 October 1967 the "Venera-4" automatic interplanetary station, having covered a distance of about 350 million km, reached Venus, made a smooth descent into its atmosphere, and obtained highly important data concerning the chemical composition of the atmosphere, its temperature and pressure, and also delivered to its surface a second pennant with the State Seal of the Soviet Union. A day later the "Mariner-V" flew by Venus at a distance of several thousand kilometers and also carried out scientific investigations.

Along its flight trajectory the "Venera-4" carried out exceptionally important physical investigations of space extremely remote from the earth. Magnetometer measurements made aboard "Venera-4" revealed that Venus has no significant magnetic field and if one does exist it is at least a thousand times weaker than the earth's. Charged-particle counters did not register any radiation belts near it similar to those discovered near the earth.

The first direct measurements of Venusian atmospheric parameters in a segment about 28 km in length revealed that the chemical composition of the Venusian atmosphere differs sharply from the composition of the earth's atmosphere. The car on dioxide concentration there is extremely high, 90%, and nitrogen constitutes only a few percent. In addition, the oxygen and water vapor content was much less than in the earth's atmosphere.

Temperature and pressure measurements in the lower layers of the atmosphere at the level reached by "Venera-4" confirmed the conclusions drawn by radioastronomers that there are high temperatures (270°C) and high pressures (18 atm). It was also established that Venus has a "hydrogen corona" similar to the earth's but it is less extensive. The results of the indirect measurements made by "Mariner-V" during its rising above and setting below the

horizon and transmitted to the earth indicated some discrepancy with the "Venera-4" data. According to "Mariner-V" data, the surface temperature could be still higher, up to 480°C, whereas the pressure was greater than 20 atm and could attain 70 atm.

All the collected data must be refined by further investigations.

For this purpose the Soviet "Venera-5" and "Venera-6" interplanetary stations were launched to Venus on 5 and 10 January 1969. After safely avoiding all dangers during the multimonth space flight, in mid-May of this same year, they reached Venus and delivered to the planet emblems with a bas-relief of V. I. Lenin and an image of the USSR State Seal. /24 During the flight both stations measured solar and galactic cosmic rays and investigated interplanetary plasma and scattered solar ultraviolet radiation. The descent modules of the "Venera-5" and "Venera-6" descended into the planetary atmosphere on its nighttime side. During descent chemical composition, pressure, density, temperature and atmospheric illumination were measured.

The new data confirmed the earlier measurements made by the "Venera-4" station and increased the accuracy of our knowledge concerning chemical composition of the Venusian atmosphere. It was established that the carbon dioxide concentration was somewhat greater than indicated by earlier data: it attains 93 - 97%. The content of nitrogen, together with other inert gases, is 2 - 5% and the quantity of oxygen is less than 1%.

The "Venera-5" and "Venera-6" stations transmitted data on temperature and pressure from deeper layers of the atmosphere than did "Venera-4" and determined the nature of the vertical temperature profile. The station reached atmospheric levels where the temperature was 325°C and pressure was 27 atm. The "Venera-5" and "Venera-6" stations made measurements when approximately 20 km still remained to the planetary surface.

Analysis of all the transmitted data revealed that at the planetary surface one may expect pressures of about 100 atm and temperatures of about 500°C.

The temperature change in virtually the entire region of measurements by the "Venera-4," "Venera-5" and "Venera-6" stations corresponded to the adiabatic law, for which vertical gas movement (convection) is characteristic. However, it was impossible to say with assurance whether this law remains in

force down to the surface or becomes different. This governs the estimate of temperature and pressure at the surface which was obtained from computations of the corresponding models of the Venusian atmosphere.

In accordance with the program for exploration of space and planets of the solar system, the Soviet Union launched the "Venera-7" automatic interplanetary station on 17 August 1970. The main objective in launching the "Venera-7" automatic station was making a landing on the planet, studying the planetary atmosphere during the course of descent to the very "bottom," and making measurements directly at the surface. In addition, in the segment of interplanetary flight provision was made for studying cosmic ray intensity.

A special apparatus which made it possible to measure temperature in the range from 25 to 540°C and pressure from 0.5 to 150 atm was carried on the descent module of the "Venera-7" station for measuring pressure and temperature in the Venusian atmosphere. /25

Since the earlier measurements by the "Venera-4," "Venera-5," and "Venera-6" stations revealed that the planetary atmosphere is extremely heated, it was desirable to explore the still uninvestigated regions as soon as possible. This was ensured by the most favorable temperature regime for the descent module of the "Venera-7" station in the main final descent segment and at the Venusian surface. Accordingly, design of the descent module parachute system was subjected to considerable changes and the "Venera-7" passed through the upper parts of the atmosphere considerably more rapidly than had its predecessors.

On 15 December 1970 the descent module of the Soviet "Venera-7" interplanetary station made a landing on the Venusian surface. On the basis of the nature of change in the measured temperatures and velocity with time, it was possible to determine the dependence of atmospheric temperature on altitude down to the very surface of the planet. It was found that the law of temperature change is close to adiabatic down to the very surface. This fact has fundamentally important scientific significance.

The successful implementation of still another important space experiment for the first time made it possible to obtain scientific information directly from the surface of another planet in the solar system.

The values of the atmospheric parameters at the planetary surface at the landing site of the "Venera-7" station descent module are: temperature $475 \pm 20^{\circ}C$, pressure 90 ± 15 atm.

Thus, it was finally established that Venus has a very heated atmosphere, whose density at the surface is approximately 60 times greater than the density at the earth's surface.

The chemical composition of the Venusian atmosphere and the physical parameters at its surface differ sharply from the terrestrial levels.

The extent of the Venusian atmosphere is about several hundred kilometers, whereas the earth's upper atmosphere extends for thousands of kilometers from its surface. Venus also has a "hydrogen corona," much like the earth's, but it has no magnetic field.

Comparison of the Earth's and Venus' atmospheres enabled scientists to conclude that the great difference in evolutionary processes transpiring on the planets led to those substantial differences in physicochemical conditions which have become established on the Earth and Venus. Precisely for this reason a study of the true physical conditions on Venus, differing sharply from the Earth's is of exceptional scientific interest. /26

By studying the earth alone it is impossible to determine the general laws of development and structure of planets in the solar system. However, if one has data on several planets which can be compared with one another, for example, the Earth, Venus and Mars, one can already determine what the general laws are and thereby come closer to solving fundamental problems in modern cosmogony. Accordingly, study of the physical characteristics of interplanetary space will enable scientists to solve problems relating to the origin and evolution of the planets, their atmospheres, magnetic fields and other different planetophysical phenomena. It is entirely understandable that today all these exciting problems can be solved only using automatic interplanetary stations sent to the planets and flying around them at a close distance or descending into the depth of their atmospheres and to their surfaces.

The exploration of Venus with automatic vehicles has been in progress for only ten years. Man has sent nine vehicles to Venus, seven of which have

been Russian. The first mysteries of Venus have been solved and much new and unique data have been obtained on the physics of its atmosphere, far more information than during the many hundreds of years of earlier investigations.

However, Venus has only drawn aside its curtain of mystery a little. It is entirely understandable that this neighboring world still hides many mysteries and therefore investigations of Venus will be continued in the future by the earth's inhabitants on a planned and successive basis.

Space Explorations of Mars

The planet Mars is the third celestial body to which space vehicles have been sent from earth.

The "Mars-1" interplanetary station was launched in our country on 1 November 1962; it was the world's first research vehicle sent to the planet Mars. Sixty-one radio contacts were made with this station and a great volume of scientific information was obtained, including data on the solar wind, magnetic fields and meteor streams. Radio communications were maintained to a distance of 106 million km, which for that time was a great achievement. Approach of the station to the planet Mars occurred on 19 June 1963. It passed the mysterious planet at a distance of 195,000 km from its surface, after which it went into a heliocentric orbit. Thus, an interplanetary trail to Mars was glazed for the first time. /27

Launching of the "Mars-1" station was at that time an important achievement of Soviet science and technology. Suffice it to mention that in putting the station into the computed trajectory, the error in direction did not exceed two seconds and at the time of approach the minimum distance between the station and the planet Mars was very close to the computed value. This was evidence of high accuracy in putting the station into the computed trajectory. Soviet radioelectronics successfully passed a difficult examination: over a long period the station's on-board systems operated and were controlled over a distance of many millions of kilometers.

The "Mariner-IV" and "Zond-2" space vehicles were launched in the direction of Mars in the United States and the USSR on 28 November and 30 November 1964 respectively. The "Zond-2" station carried an instrument package, long-range communications system, and an orientation system. In particular, for the first time in history the orientation system included electrojet engines which had undergone successful tests under spaceflight conditions. During flight of the "Zond-2" station a great volume of valuable scientific information was obtained.

In July 1965 the "Mariner-IV" passed the Martian surface at a distance of 1,200 km and photographed it from a distance of 12,600 - 17,000 km.

The "Mariner-VI" and "Mariner-VII" space vehicles were launched in the direction of Mars from the United States in February and March 1969. The objective of flights of these vehicles was conducting further scientific investigations of the planet.

It was established as a result of the investigations made by these space vehicles that Mars is surprisingly similar to the moon. Its landscape is also a desert and the surface is similarly studded with craters. It has no protection against bombardment by hard radiation. Analysis of composition of the Martian atmosphere revealed that it contains no nitrogen, without which terrestrial life cannot exist. Atmospheric pressure does not exceed 5 - 10 mm Hg. Some photographs show that the crater slopes are covered by light-colored formations reminiscent of glaciers or avalanches. Since the planetary atmosphere contains no water, or there is almost none, it has been postulated that these formations are frozen carbon dioxide and as is well known, solid carbon dioxide is toxic for all forms of terrestrial life. Accordingly, Mars is evidently as lifeless a celestial body as the moon.

As already mentioned, this year of 1971 is the year of the great opposition of Mars. On 10 August the distance between it and the earth was only 56.2 million km. It is entirely understandable that this period is particularly favorable for a new attack on Martian secrets. Indeed, Mars can be /28
observed with telescopes and using them one will be able to distinguish on its surface many more details than at any other time. Since more than 15 years have passed since the preceding minimum approach, and since during this time observation methods and instruments have been considerably improved, there is every basis for assuming that the great opposition will make it possible to obtain new and interesting information concerning Mars.

This year is also favorable for launching automatic stations to Mars. Their flight along the most advantageous trajectory requires a definite position of Mars relative to the sun and earth. Such a condition, favorable with respect to energy expenditures, arose in May of this year. Precisely for this reason, on 19 and 28 May our country launched the new "Mars-2" and "Mars-3" interplanetary stations. In order to reach the neighborhood of Mars, the automatic stations had to fly a distance of about 470 million km; this required more than six months. In the first flight stage the "Mars-2" and "Mars-3"

in their motion in elliptical orbits around the sun will outrun the launching site, the earth, but together with it will lag behind Mars. Gradually our planet and the automatic stations are beginning to overtake our mysterious neighbor and then all three at definite times will be in a single straight line connecting them with the sun. Then the earth, being the most rapid in its constant revolution around the sun, will outpace both the automatic stations and Mars.

The distance between them will begin to increase. However, when "Mars-2" and "Mars-3" approach the final goal of their journey, the earth will be situated in such a position in its orbit as will ensure convenience in radio communication with its automatic emissaries. The station on-board radiotelemetric systems will ensure transmission of different kinds of scientific and technical information to the earth. Conquest of the flight trajectory, conducting astronavigation sessions and carrying out scientific investigations of the planet Mars and the space surrounding it -- such is an imcomplete list of those missions which it is proposed be solved using the interplanetary stations "Mars-2" and "Mars-3." Late in May the American spacecraft "Mariner-IX" was launched to Mars.

Such are the principal results of space investigations of the three celestial bodies of the solar system closest to the earth which man has obtained after launching of the automatic interplanetary stations.

The collected information surpassed the most gloomy forecasts. The Moon and Mars are lifeless space bodies. The world of Venus was such as to make it difficult to visualize what is happening on its red-hot surface at a monstrous atmospheric pressure.

The following questions involuntarily arise: if the celestial bodies /29
closest to us constitute formations of dead matter, why investigate them? Is it desirable to expend money and time on space flights when these could be used in solving many terrestrial problems?

However, the fact is that in order to improve man's life on the earth one must study its sources. Our planet is not isolated from other objects in the universe. It is connected by thousands of strands with different processes transpiring in space. Space research will assist in clarifying the causal relationship between terrestrial events and extraterrestrial events.

Lunar investigations constitute the only possibility for experimentally checking a number of fundamental concepts based only on what we know about the earth. In addition, such investigations constitute an important source of new hypotheses in the most different areas of our terrestrial knowledge. This is one of the principal goals and the sense of planetary investigations using rocket-space technology. In space man also strives to find the answers to such fundamental questions as the structure and evolution of the universe, formation of the solar system, and origin and path of development of life.

When we study the earth we deal only with one planet, but in investigations of but a single planet it is impossible to formulate general laws of development of the planets, to differentiate the regular from the random, the general from the individual. This requires data on several planets so that they can be compared with one another, so that they can be generalized, and so we can deduce all their distinguishing characteristics.

The hypothesis of a common origin of bodies in the solar system gives rise to a great number of problems whose solution is dependent to a considerable degree on the level of our ideas concerning each of these bodies. The gradual accumulation of experimental data on individual planets means an important step forward in learning the laws applicable to the entire solar system.

Science now postulates that the very same process led to formation of the sun and planets. If their formation transpired in parallel, their primary composition should be completely identical. However, the bodies of the solar system differ sharply in composition, the planets from the sun and even planets of the same group (Venus, Earth, Mercury, Mars) from one another and from the giant planets (Jupiter, Saturn, Neptune, Uranus). One of the most important problems in planetology is study of all the planets using all the different kinds of tools and methods for ground and space investigations.

Cosmonautics has travelled a long distance in space research: from the /30
small-in-weight first earth satellites to flights of automatic stations to other celestial bodies and manned flights to the moon.

From an epoch of hypotheses concerning the nature of the planets and the structure of space, based on ground observations, man has proceeded to a

many-sided study of celestial bodies and interplanetary space in the solar system using rocket-space technology.

It is beyond question that using both manned and unmanned space vehicles man sooner or later will be able to solve many mysteries concerning the planets of the solar system and will exploit them for his welfare.

Space Exploration of Tomorrow

The fourteenth year of the space era has been completed. During this unprecedentedly short time cosmonautics has become one of the principal links in modern scientific and technical progress.

It was found that space is interesting and necessary for everyone. More than 1,000 space objects have been launched into circumterrestrial space by different countries: USSR, United States, Great Britain, France, Canada, Italy, Japan and China. Dozens of countries are participating in conducting joint experiments within the framework of international cooperation and commercial programs.

Space research has laid the basis for new attainments in the most different branches of human knowledge. This research is characterized by a complex approach to solution of problems, the use of the latest advances in science and technology, and a high degree of automation.

Man's penetration into space is a natural step in world scientific and technical progress. In addition to exploitation of the natural resources of our own planet, the oceans, and atmosphere, man inevitably had to begin an attack on space, a new and unstudied medium which plays an important role in the life of man and all living things.

How necessary is man's direct participation in these investigations and his flights into space in manned vehicles?

The opinion prevails that automatic vehicles are the vanguard, the first scouts, sooner or later to be followed by man. This is not entirely the case. The planets of the solar system will long remain the "realm" of automatic vehicles. It is without question that the investigations conducted on the surface or from the surface of other planets will be carried out primarily by automatic station-laboratories and that the planets themselves will long remain "inaccessible regions" for us.

There has still been no adequate study of the possibility of man's productive activity on other planets. Even with the presence of all conditions necessary for his vital functions the implementation of prolonged investigations on the surface of planets with man's direct participation will scarcely be justifiable.

To these considerations one must always add the random dangers to which man is exposed on space journeys. Moreover, as long as the power of space vehicles launched from the earth is not increased there is a definite limit on the "payload" which a space vehicle can put into interplanetary trajectories and orbits. It is clear that when the weight of the ship's crew and all /31
its life support systems is included in this payload the scope of the scientific program is restricted because the number of research instruments used for this purpose is limited.

What are the most important objectives in modern space programs carried out by the earth's inhabitants using different vehicles? In general, they can be summarized as follows: attaining a fundamentally new level of our knowledge concerning the universe as a whole and in particular concerning the regions surrounding our planet.

Among the most important objectives of modern cosmonautics the most important are investigations of the present state of the solar system for the purpose of learning the laws of its origin and further development. In this case reference is primarily to study of the chemical composition and physical characteristics of the atmospheres and surfaces of the planets and their satellites, exploration of their interiors, determining more precisely the size and mass of bodies in the solar system, investigation of fluxes of solar corpuscular and electromagnetic radiation, magnetic fields and cosmic dust in the solar system.

From the vantage point of today it is difficult to predict the specific problems which will be solved by cosmonautics in the not-distant future. It is also difficult to predict the scientific-technical problems and the problems which will become a reality in the immediate future. Accordingly, only general considerations can be expressed concerning the future objectives of space programs.

Investigations of regions of the solar system lying outside the plane of the ecliptic would be of great scientific interest. However, the launching of space vehicles on trajectories forming a great angle to the plane of the ecliptic will still remain impossible for a long time. With small angles of inclination a space vehicle theoretically can withdraw for great distances from the plane of the ecliptic, but this will occur far from the center of

the solar system. Thus, the regions of space located "above" and "below" our sun will still for a definite time remain unattainable for us. Moreover, even flights in the plane of the ecliptic to the neighborhood of the sun, due to the great energy expenditures, are quite complex programs. However, exploration of regions more distant from the sun, such as those lying within the orbit of Mercury, will evidently be possible in the near future.

For example, in 1973 American scientists plan to launch a "Mercury" spacecraft for exploring the planet closest to the sun from a fly-by trajectory. The vehicle's flight trajectory to Mercury should pass Venus at a distance of 4,000 - 6,700 km. A double objective is in mind: first, the Venusian atmosphere will be probed; second, under the influence of Venusian attraction the vehicle will be imparted additional velocity of motion and will head for Mercury. The vehicle should fly around Mercury at a distance of approximately 3,000 km, photograph the planetary surface, determine its thermal characteristics, and explore its atmosphere, magnetic field and radiation belts. On this vehicle it will be entirely possible to carry a special separable probe which can be sent down to the Mercurian surface.

In the not distant future space vehicles will undoubtedly become satellites of Mars and Venus, where, revolving over a long period, they can make radar observations and map their surfaces.

Many scientists feel that the creation of balloon-probes drifting in the Venusian atmosphere is one of the priority goals in space technology. Another important scientific-technical problem is making a soft landing of spacecraft on the celestial bodies closest to the earth. This problem has already been successfully solved by cosmonautics for the Moon and Venus. Without repeated landings on the surface of the Moon, Venus, Mars and Mercury /32 it will be impossible to obtain reliable data concerning the composition of the rocks making up their surface, the composition, density, pressure and temperature of the lower layers of the atmosphere in different regions, and also the possible detection of evidence of actual presence of life on these celestial bodies.

It is of great interest to study the satellites of Mars, whose mysterious properties even induced the well-known Soviet astrophysicist I. S. Shklovskiy to suggest that they are of artificial origin.

During the second half of the 1970's there will be very exceptional possibilities for the launching of automatic stations in the direction of distant planets of the solar system: Jupiter, Saturn, Uranus, Neptune and Pluto. The relative position of the planets will be favorable for a single interplanetary station to fly by several planets successively, using their attraction for both a so-called perturbation maneuver, which will direct the station to the next planet almost without expenditure of fuel, and will also shorten flight duration.

The next time when such a favorable arrangement of the planets occurs for a successive fly-by will not be until the mid-21st century or even the mid-22d century. The program for the successive flight of a space vehicle past several distant planets of the solar system is interesting. A space vehicle sent along such a marathon trajectory can also carry separable probes for descent to the surfaces of the investigated planets. As the vehicles successively approach the planets a wide variety of investigations can be made: soundings of their atmospheres, photographing the planets, measurements of radiation belts and magnetic fields, etc. It must be assumed that man will not let this favorable possibility go by, since it will not be repeated in this century.

It is entirely probable that space investigations of both near (relative to the earth) and distant planets and their satellites may yield much unexpected information. This applies, in particular, to the problem of the origin and development of life.

The asteroids and comets are also of great interest for investigation. Fly-bys or even landing on the asteroids and photographing of comets from close distances no longer present fundamental difficulties for the modern development of cosmonautics.

Using several brief examples we have attempted to characterize the future of cosmonautics. It would be possible to cite a quite large number of other space projects with different objectives, purposes and possibilities, discussed by specialists. However, evaluations in detail would be extraneous and as usual they are debatable. The authors had a different objective: to suggest the idea that man has emerged into space not out of idle curiosity, but for the purpose of exploiting it and employing its limitless expanses as he sees fit.

NASA-Langley, 1973 —— 30 F-767

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